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DUSTING TOMATO SEED WITH COPPER SULFATE MONOHYDRATE FOR COMBATING DAMPING-OFF

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TECHNICAL BULLETIN No. 198

DUSTING TOMATO SEED WITH COPPER SULFATE MONOHYDRATE FOR COMBATING DAMPING-OFF

JAMES G. HORSFALL

ABSTRACT

Data are presented showing that copper sulfate monohydrate is effective as a seed treatment for combating damping-off of tomatoes caused by *Pythium ultimum;* more effective than either copper sulfate soak or copper carbonate dust in controlling the pre-emergence phase of the disease, thus increasing stands; and less effective than the former but more effective than the latter in decreasing incidence of disease on emerged seedlings. The material has been demonstrated to be commercially non-injurious to tomato seedlings, altho copper compounds were shown to retard emergence slightly in steamed soil. Its effectiveness does not appear to be reduced by dilution to 25 per cent in kaolin. Anhydrous copper sulfate is equally good as a seed treatment, and adheres somewhat better.

A new term, "inoculum potential", is defined to show the influence of the pathogenic-fungus content of the soil on severity of infection irrespective of environmental factors. The term, "steamed soil" is preferred to "sterilized soil", since it seems to be more accurate.

INTRODUCTION

This paper is the fourth in a series of reports, each covering a phase of the writer's work on damping-off of vegetable seedlings, particularly tomatoes.[1] In the first and second of these reports the proposal was made to soak tomato seed in a copper sulfate solution as a means of increasing emergence and combating damping-off of the emerged seedlings. The third report, published as Circular No. 120 of this

[1]Horsfall, James G. Seed treatment for damping-off of tomatoes. *Phytopath.*, **21**: *105. 1931.*

————. Combating damping-off of tomatoes by seed treatment. *New York State Agr. Exp. Sta. Bul. No. 586. 1931.*

————. Damping-off of tomatoes combated by seed treatment with copper compounds. *New York State Agr. Exp. Sta. Circ. No. 120. 1931.*

Station, suggested in a very brief and popular way that dusting tomato seed with copper sulfate monohydrate might be substituted as a matter of convenience for the copper sulfate soak. Since these treatments have met with considerable favor among growers in many sections, the experimental data behind the recommendation of copper sulfate monohydrate are presented in this paper.

The same fungus that was involved in the tests reported in the previous papers was responsible for the damping-off in the experiments reported herein. In the earlier papers, the fungus was identified provisionally as *Phytophthora* sp. Since their publication, however, the fungus has been identified by E. L. Felix, Department of Plant Pathology, Cornell University, as *Pythium ultimum* Trow. It seems probable that *Rhizoctonia solani* was not of any great importance in the causation of the disease in these tests.

OBJECT OF THE INVESTIGATION

The studies reported here have been limited to the seedling flat since obviously a seed treatment must lose most of its force when the seedlings are transplanted. The treatments may, and many growers believe that they do, exercise an indirect effect on disease in the transplanted seedlings by enabling them to enter that phase of their existence in a more nearly disease-free condition.

Any seed treatment program seems more likely to succeed with the growers if it can be used dry, i. e., applied as dust, than if soaking is necessary. The reasons for this are ease of operation, time saved, and messiness reduced. With the idea in mind of finding a dry seed treatment the possibilities of copper dusts, especially inexpensive ones, were scanned. Copper sulfate monohydrate was one of those chosen for extensive study. It was tested for efficacy and injuriousness under a wide range of conditions, and has been compared with the copper sulfate soak and with copper carbonate as standards of reference.

MATERIALS AND METHODS

Approximately the same experimental technic was employed in these tests as in those previously described.[2] Supposedly healthy seed of the variety John Baer was used in all cases. In order to have a large number of seedlings together, thus favoring damping-off as in

[2]Bulletin No. 586 of this Station.

commercial plantings, the standard flat or tray, 14 x 22 x 3 inches, filled with normally composted greenhouse soil, was used as the experimental unit, unless otherwise stated. These flats were placed on greenhouse benches where the temperature ranged around 15°C. Seed for these experimental units was measured in a 30-mm shell vial rather than counted in order to save labor. For any particular lot of seed (usually 2 pounds), the number in a shell vial was determined to the nearest 50 from an average of three actual counts. Experience showed that this was a satisfactory method of sowing equal numbers of seeds, so that this was not a limiting factor in obtaining sound data. All treatments for any one experiment were made in duplicate. Unless otherwise stated, the soil was kept uniformly almost soaked for each test in order that optimum moisture conditions for damping-off might prevail.

In applying the dust, two measures of seed were placed in a 250-ml Erlenmeyer flask. Dust was added in excess with a spatula. The flask was then shaken thoroly until each seed was coated with all the dust that it would carry. The seeds were then poured out onto a 20-mesh screen to remove the superfluous dust. In planting it was then necessary to remeasure only one of the two lots of seed for one flat and to plant the remainder in the duplicate flat. Even tho the number of seeds in a measure might have been reduced slightly by the load of dust, the full two measures were sown. By this method no seeds were wasted, a factor of importance in consideration of the fact that $40 worth of seed is used each season in this work. To date (Autumn 1931) 12 pounds of tomato seed containing 1,920,000 seeds have been measured and planted. These have produced approximately 1,440,000 seedlings each of which has been handled. This does not include seedlings kept under observation in commercial greenhouses. In working with this number of seedlings considerable experience was gained with damping-off.

For several reasons, enumerated below, the writer has depended for most of the results with damping-off upon naturally contaminated soil which was used repeatedly in order to build up a high fungus content or *inoculum potential*.[3] First, in the Station green-

[3]It seems desirable to define the term "inoculum potential" as used in this bulletin. It was chosen to describe one of the concepts necessary in contemplating the phenomena involved in the destruction of the roots by soil-borne organisms. Certainly some soils contain more of these pathogenic organisms or a larger content of some one of them than do other soils. The increase in the incidence

houses, at least, the soil is fairly uniformly contaminated with *Pythium ultimum*. Second, the experimental technic is simpler and can be handled better with available labor since precautions against accidental contamination are unnecessary. Third, since steaming and the addition of inoculum is not required, less time is consumed with each test, so that more tests can be made, and thus more significant results can be obtained. Fourth, artificially contaminated soil may acquire other organisms under the usual greenhouse conditions. Fifth, artificial contamination imposes a much more drastic test than the treatments are usually called upon to undergo. The presence of large amounts of fungus in artificially contaminated soil may sometimes almost obliterate the significance of a treatment that might be considered efficacious in a commercial greenhouse. Sixth, since the different phases of the disease may be caused by different micro-organisms or micro-organism complexes, the effects of these do not appear in soil artificially contaminated with one fungus alone.

Of course, results obtained with naturally contaminated soil should be, and have been, checked by using autoclaved soil alone and after contamination with pure cultures. The recent addition of a huge canning retort[4] to the equipment of the Station has permitted these

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of damping-off when the same soil is used repeatedly seems to be associated with an increase in the pathogenic-fungus content or inoculum potential of the soil.

Inoculum potential seems to be a term that may be used logically to denote variations in the content of pathogenic fungi or inoculum in the soil that result in corresponding variations in disease expression. This term is applicable only to a single host and a single fungus. Recently, Wilson (*Phytopath.*, **22**: *30. 1932*) has presented evidence showing that variations in the quantity of inoculum influence the severity of the attack of *Fusarium niveum* on watermelons in the field. In the case of damping-off of tomatoes, for example, the inoculum potential for *Pythium ultimum* may be different in any given soil from that for *Rhizoctonia solani*.

The word, "potential" in the phrase indicates the amount of such organisms present. Such a concept carries with it the idea of mass action—the greater the mass of the organism present, the more severe will be the disease. This concept also concerns itself with the idea of virulence—the more virulent the organism, the more severe will be the disease. This view of inoculum potential is concerned only with the influence of the amount or virulence of the inoculum rather than with the influence of environment on severity of infection.

When the inoculum is sufficiently plentiful or virulent in a given soil to induce a severe infection on tomatoes, the "inoculum potential" is high. If, on the other hand, only a mild case is induced in the same soil under the same environmental conditions, then the "inoculum potential" is low.

[4]The writer is indebted to the American Can Co., and especially to its representatives Messrs. Perry Wilson and Harry Kaeselow, for furnishing the retort for this work.

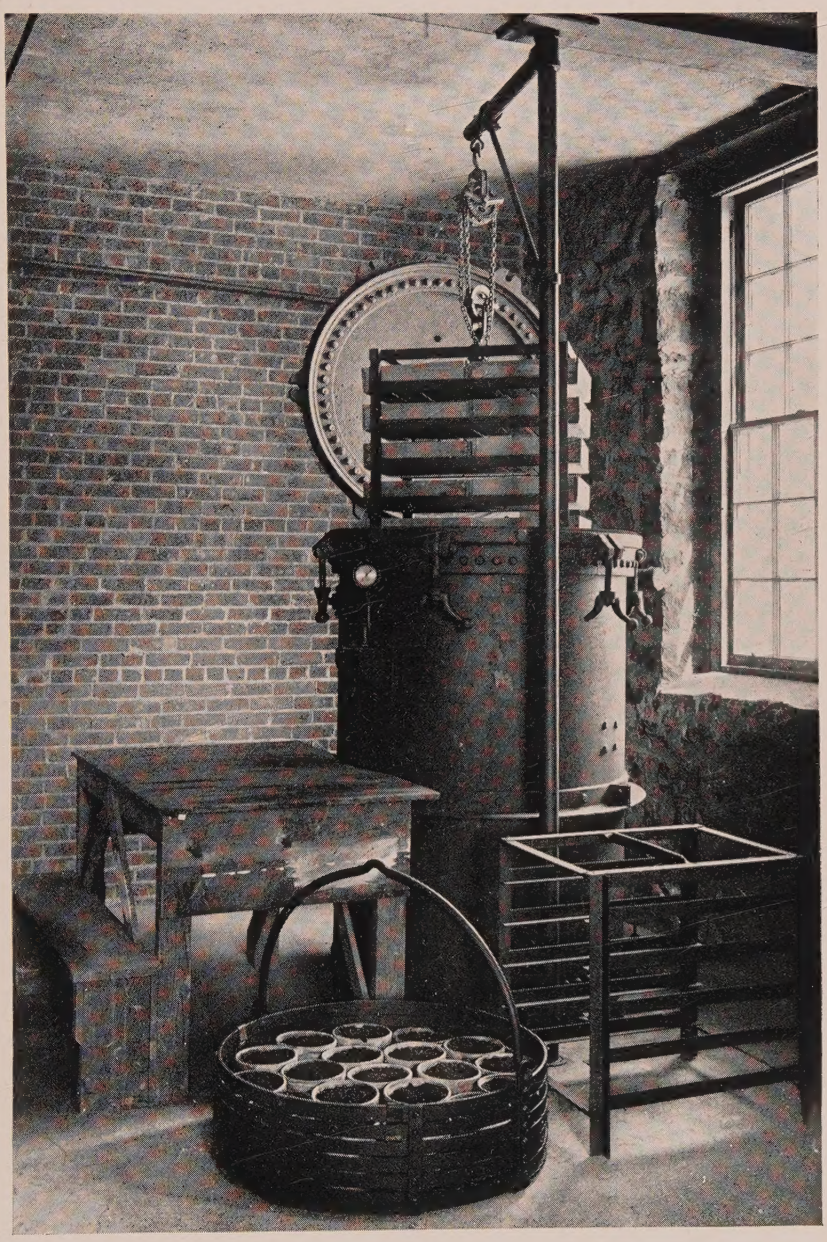

FIG. 1.—CANNING RETORT FITTED UP AS A SOIL AUTOCLAVE.

A rack filled with flats appears suspended from the crane over the opening to the autoclave. Another rack is shown at the right foreground. The container in the center foreground designed to hold cans, serves admirably for steaming soil in pots.

contributory studies. Because of its relative cheapness, the retort will be described here. It is illustrated in Fig. 1. It is a vertical cylinder 36 inches in diameter and 56 inches high inside. It was commissioned as a soil autoclave by constructing two angle-iron racks, with a combined capacity of 20 standard greenhouse flats, each separated by a space of 2 inches from its neighbors above and below. One of these racks filled with flats of soil appears in Fig. 1 hanging from the crane over the opening to the autoclave. An empty rack sits on the floor. Pots of soil may be steamed in the container designed to hold the cans as shown in the center foreground of the photograph. The soil containers are hoisted into the retort by means of a hand-operated crane. A reducing valve on the steam line maintains a pressure inside the autoclave constant within ½ pound per square inch.

In all cases where steamed soil was used, it was autoclaved for 1½ hours at 25 pounds pressure.[5]

In measuring the degree of control of damping-off it was assumed that the disease expresses itself in two rather distinct phases, *viz.*, the destruction of the seeds and seedlings prior to emergence or the pre-emergence phase, and the destruction of the seedlings after they are up or the post-emergence phase. No attempt was made to separate the pre-emergence phase into its two components, *viz.*, rotting of ungerminated seeds and the destruction of sprouts before they could emerge. This distinction could have been made partially by subtracting the percentage of emergence from the percentage of germination as obtained in the seed laboratory. As it was, the severity of the pre-emergence phase of damping-off in the checks was expressed as a number obtained by subtracting the percentage of total emergence from 100. For the treatments, the severity of the pre-emergence phase was expressed as percentage of the check, thus making some correction for varying environmental conditions. In the previous paper this phase of the disease was expressed as percentage of emergence rather than as percentage of individuals destroyed. Figures for percentage of emergence do not represent precisely what is needed to express the activity of pathogenic soil-borne micro-organisms in producing disease. Such figures place the emphasis on the lack of disease rather than on its presence, where it belongs.

[5]Since steaming soil for 1½ hours at 25 pounds probably does not sterilize it completely, the term "steamed soil" is used here in preference to "sterilized soil."

The severity of the post-emergence phase of the disease in the check was expressed as percentage of emerged seedlings that were diseased. This percentage included both the seedlings that had actually damped-off as well as those that had spots on their roots indicating the incipient stages of damping-off. Since this number gives no measure of the destructiveness of the disease on individual plants, it is only partially indicative of the severity of the post-emergence phase of damping-off.

EXPERIMENTAL RESULTS

NATURALLY CONTAMINATED SOIL

COMPARISON OF COPPER SULFATE MONOHYDRATE WITH STANDARDS

In obtaining experimental data on the efficacy of copper sulfate monohydrate as a seed treatment, it was compared in the same test either with the previously recommended copper sulfate soak, with copper carbonate dust, or with both. Data thus obtained from six such tests appear in Table 1 and are depicted graphically in Fig. 2.

The averages appearing at the bottoms of the columns headed "Average Percentage of Check" in Table 1 were weighted as described in an earlier paper[6] to allow partially for variations in the inoculum potential, temperature, moisture, and other conditions that occurred in the various tests.

The figures thus obtained and set down in Table 1 confirm those presented previously, showing that seed treatment with copper compounds is valuable in combating both phases of damping-off. Seed treatment prevents the destruction of the seeds and unemerged seedlings in the soil by the organisms present there and thus increases the stand. It seems also to protect the seedlings to a large extent from the inroads of micro-organisms after they emerge. Table 1 further confirms the conclusion that copper carbonate dust is less effective than the soak in combating either of the phases of damping-off and is relatively less effective in combating the post-emergence than the pre-emergence phase. This is shown by the fact that the ratio between the weighted averages for the copper sulfate soak and the copper carbonate dust is 1.51 for pre-emergence disease and 3.50 for post-emergence disease. The figures in this table seem to indicate also that copper sulfate monohydrate dust in general is more effective than the copper sulfate soak in controlling the pre-emergence phase

[6]Bulletin No. 586 of this Station.

TABLE 1.—COMPARISON OF COPPER SULFATE MONOHYDRATE DUST WITH COPPER BATING DAMPING-OFF OF TOMATOES

No. of experiment	Check (untreated)			Dusted with copper sulfate monohydrate				
		Diseased			Diseased			
					Pre-emergence		Post-emergence	
	Emergence, per cent	Pre-emergence, per cent	Post-emergence, per cent	Emergence, per cent	Per cent	Average per cent of check	Per cent	Average per cent of check
				September 26, 1930				
1	52.7	47.3	30.0	85.6	14.4		10.5	
1	60.7	39.3	50.5	90.6	9.4		6.0	
Av.	56.7	43.3	40.3	88.1	11.9	27.5	8.3	20.6
				October 1, 1930				
2 a	48.2	51.8	72.0	73.0	27.0		11.0	
2 b	63.1	36.9	56.5	80.0	20.0		12.5	
Av.	55.7	44.3	64.3	76.5	23.5	53.0	11.8	18.3
2 c	——	——	——	——	——		——	
2 d	——	——	——	——	——		——	
Av.	——	——	——	——	——	——	——	——
				October 15, 1930				
3 a	64.3	35.7	24.5	83.6	16.4		15.5	
3 b	48.8	51.2	47.5	93.5	6.5		28.0	
Av.	56.6	43.4	36.0	88.6	11.4	26.3	21.8	60.5
				October 23, 1930				
4 a	16.2	83.8	87.5	83.2	16.8		10.0	
4 b	18.2	81.8	79.0	76.6	23.4		51.0	
Av.	17.2	82.8	83.3	79.9	20.1	24.3	30.5	36.6
				November 12, 1930				
5 a	42.8	57.2	94.0	81.5	18.5		58.0	
5 b	44.2	55.8	63.0	76.9	23.1		16.5	
Av.	43.5	56.5	78.5	79.2	20.8	36.8	37.3	47.5
				November 14, 1930				
6 a	46.8	53.2	46.5	81.1	18.9		62.5	
6 b	45.3	54.7	77.0	83.4	16.6		26.0	
Av.	46.1	53.9	61.8	82.3	17.7	32.8	44.3	71.7
Grand average...	45.9	54.1	60.7	82.4	17.58	33.45	25.63	42.53

*5 grams $CuSO_4 \cdot 5 H_2O$ dissolved in 100 cc water.
†15 grams $CuSO_4 \cdot 5 H_2O$ dissolved in 100 cc water.
‡50 grams $CuSO_4 \cdot 5 H_2O$ dissolved ln 100 cc water.
§10 grams $CuSO_4 \cdot 5 H_2O$ dissolved in 100 cc water.

SULFATE SOAK AND COPPER CARBONATE DUST AS A SEED TREATMENT FOR COM-IN NATURALLY CONTAMINATED SOIL.

SOAKED 1 HOUR IN COPPER SULFATE SOLUTION					DUSTED WITH COPPER CARBONATE				
	Diseased					Diseased			
	Pre-emergence		Post-emergence			Pre-emergence		Post-emergence	
Emergence, per cent	Per cent	Average per cent of check	Per cent	Average per cent of check	Emergence, per cent	Per cent	Average per cent of check	Per cent	Average per cent of check
					September 26, 1930				
85.7*	14.3		2.0		71.5	28.5		26.0	
81.5*	18.5		5.5		87.7	12.3		16.5	
83.6	16.4	37.9	3.8	9.4	79.6	20.4	47.1	21.3	52.8
					October 1, 1930				
58.1†	41.9		25.0		59.9	40.1		18.0	
76.9†	23.1		5.0		67.8	32.2		8.0	
67.5	32.5	73.4	15.0	23.3	63.9	36.1	81.5	13.0	20.2
66.6*	33.4		34.0		——	——		——	
77.2*	22.8		16.0		——	——		——	
69.7	28.1	63.4	25.0	38.9	——	——	——	— -	— —
					October 15, 1930				
86.0‡	14.0		8.5		64.3	35.7		20.0	
85.9‡	14.1		1.0		71.9	28.1		27.0	
86.0	14.0	32.3	4.8	13.3	68.1	31.9	73.5	23.5	65.3
					October 23, 1930				
70.6§	29.4		29.0		30.3	69.7		76.5	
66.5§	33.5		18.0		28.0	72.0		88.5	
68.6	31.4	37.9	23.5	28.2	29.2	70.8	85.5	82.5	99.0
					November 12, 1930				
76.2§	23.8		17.0		54.6	45.4		88.5	
64.6§	35.4		28.0		55.4	44.6		82.5	
70.4	29.6	52.4	22.5	28.6	55.0	45.0	79.6	85.5	108.9
					November 14, 1930				
——	——		——		52.3	47.7		34.5	
——	——		——		60.1	39.9		38.0	
——	——	——	——	——	56.2	43.8	81.3	36.3	58.7
75.9	25.35	49.55	15.75	23.61	58.65	41.35	74.75	43.66	67.49

of the disease, but less effective in controlling the post-emergence phase. This is shown by the fact that the ratio between the weighted averages for the copper sulfate monohydrate dust and the copper

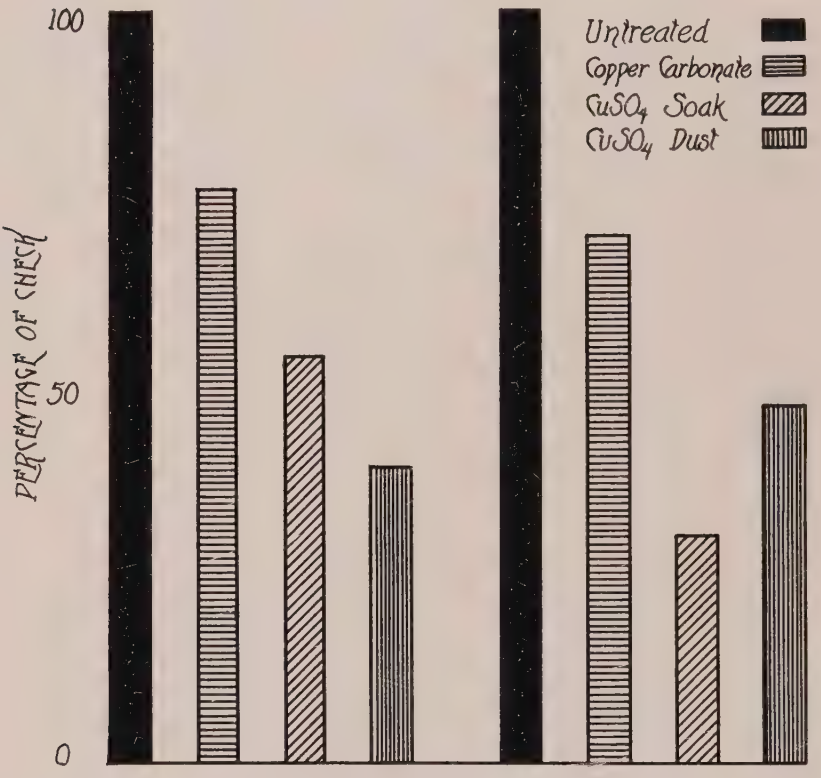

FIG. 2.—COMPARISON BETWEEN COPPER SULFATE MONOHYDRATE DUST, COPPER SULFATE SOAK, AND COPPER CARBONATE DUST AS SEED TREATMENTS FOR COMBATING DAMPING-OFF OF TOMATOES IN GREENHOUSE SOIL.

Pre-emergence disease at the left, post-emergence disease at the right.

sulfate soak is 0.68 for the pre-emergence phase and 1.80 for the post-emergence. A discussion of the significance of this phenomenon appears later in this paper. A photographic comparison of seedlings from seeds treated with copper sulfate monohydrate dust and seedlings from untreated seeds appears in Fig. 3.

In view of the implications that the results set forth in Table 1

might convey, the data were treated statistically to determine their significance. Two different methods of comparing the treatments were used to determine how the present experiments as well as later tests should be compared for the best interpretation of the results.

FIG. 3.—EFFECT OF SEED TREATMENT WITH COPPER SULFATE MONOHYDRATE DUST IN COMBATING DAMPING-OFF OF TOMATOES IN GREENHOUSE SOIL.

See experiment No. 3b in Table 1. A, a flat of 1,870 seedlings from 2,000 dusted seeds; B, a flat of 976 seedlings from 2,000 untreated seeds.

In one case, the mean for each treatment was a simple arithmetical average of the percentages of disease on which were based the differences between the treatments. In the second case, the mean for each treatment was weighted according to the average percentage of the check in each separate test, and the differences between the treatments were based on these means. Such a comparison of methods would show, for example, whether the weighted average were more accurate than the unweighted average, as had been thought. The data on both pre-emergence and post-emergence disease control for all three treatments were arranged and calculated alike. These are presented in Table 2.

TABLE 2.—BIOMETRICAL COMPARISON OF COPPER SULFATE MONOHYDRATE DUST, COPPER SULFATE SOAK, AND COPPER CARBONATE DUST AS SEED TREATMENTS FOR COMBATING DAMPING-OFF OF TOMATOES IN NATURALLY CONTAMINATED SOIL.

BASIS FOR MEAN	COPPER SULFATE MONOHYDRATE		COPPER SULFATE SOAK		COPPER CARBONATE DUST		DIFFERENCE BETWEEN								
	Mean	Error of mean	Mean	Error of mean	Mean	Error of mean	Monohydrate and soak	E_d	$\frac{D}{E_d}$	Copper carbonate and soak	E_d	$\frac{D}{E_d}$	Copper carbonate and monohydrate	E_d	$\frac{D}{E_d}$
Pre-emergence Disease															
Arithmetical for all figures	17.58	3.78	23.35	5.47	41.35	9.02	5.77	6.65	0.86	16.00	10.54	1.52	23.77	9.78	2.43
Weighted for percentage of check	33.45	3.07	49.55	5.49	74.75	3.89	16.10	6.29	2.56	25.20	6.73	3.74	41.30	4.96	8.33
Post-emergence Disease															
Arithmetical for all figures	25.63	6.52	15.75	3.59	43.66	9.87	9.88	7.45	1.33	27.91	10.50	2.66	18.03	11.83	1.52
Weighted for percentage of check	42.53	5.91	23.61	3.16	67.49	8.94	18.92	6.70	2.82	43.88	9.48	4.63	24.96	10.72	2.33

The probable error of the mean was calculated according to the formula $E_m = 0.6745 \sqrt{\frac{\Sigma (v-g)^2}{n} - c^2}{n-1}$. The probable error of the difference between two treatments was calculated according to the formula $E_d = \sqrt{(E_{m1})^2 + (E_{m2})^2}$. The difference between two treatments was considered significant if it was more than three times its own probable error.

Of the two methods shown in Table 2 for calculating the differences, that using the weighted average was statistically the more significant as shown by the fact that the error of the difference between any two treatments was always less and the quotient obtained by dividing the difference by its probable error was always more for both the pre-emergence and the post-emergence phases of the disease when the weighted average was compared with the simple arithmetical average. The reason for this lowering of the probable error by weighting was simply that the different tests were made under different conditions, so that reference to the check should be made in each case. Thus, it was shown that data on different seed treatments for damping-off control should be based on the average percentage of the check weighted according to the several experiments.

Table 2 shows that only small confidence, if any, can be placed in the figures for differences between the monohydrate dust and the soak. For pre-emergence control the difference in favor of the dust is only 2.56 times its probable error. For post-emergence control the difference in favor of the soak is 2.82 times its probable error. These figures may be considered as indications, but they are not statistically significant. It is obvious, however, that both the monohydrate dust and the soak are significantly better than the copper carbonate dust for controlling the pre-emergence phase. The monohydrate dust does not appear to be significantly better than the carbonate dust for post-emergence control, altho the soak is certainly better than the carbonate dust for this phase of the malady.

Since, as pointed out in the first paper of the series, tomato seeds seem to possess a remarkable resistance to copper toxicity, an attempt, as represented in experiment No. 3 in Table 1, was made to determine, if possible, whether any appreciable injury could be induced by soaking the seeds in a saturated solution of copper sulfate. Accordingly, 500 grams of crystalline c. p. copper sulfate were dis-

solved in 1000 ml of heated distilled water, into which the seed lots were placed when the solution had cooled to 35°C. Two lots of seeds were left in this solution for 1 hour and two lots for 2 hours and were then planted without rinsing. The solution was so thoroly saturated with copper sulfate that crystals appeared when the liquid cooled to room temperature, and yet no apparent injury to the seeds or seedlings occurred, as can be determined by referring to Table 1. No studies have been made to determine the permeability of the seed coat to copper.

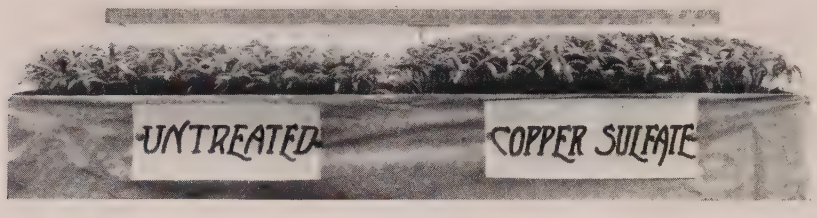

FIG. 4.—INCREASE IN VIGOR OF TOMATO SEEDLINGS FROM SEEDS TREATED WITH COPPER SULFATE MONOHYDRATE.

Untreated seeds sown in the flat on the left, and dusted seeds sown in the flat on the right.

Alexander, *et al.*,[7] found that soaking tomato seeds in a saturated solution of copper sulfate was not appreciably injurious. The fact has been noted frequently during these studies that seedlings from seed treated with copper compounds have darker green leaves and grow taller in the same length of time than seedlings from untreated seed. An instance of the increased vigor of seedlings from seed treated with copper sulfate monohydrate appears in Fig. 4. There is no doubt of the existence of the phenomenon, but the explanation is more elusive than the fact.

RESULTS IN COMMERCIAL GREENHOUSES

During the spring of 1931 copper sulfate monohydrate dust was tested in nine commercial greenhouses in western New York under the conditions prevailing there for producing the plants. The results from this series of tests appear in Table 3.

[7]Alexander, L. J., Young, H. C., and Kiger, K. M. The causes and control of damping-off of tomato seedlings. *Ohio Agr. Exp. Sta. Bul. No. 496. 1931.*

TABLE 3.—EFFECT OF SEED TREATMENT WITH COPPER SULFATE MONOHYDRATE DUST UPON THE PRE-EMERGENCE SEVERITY OF DAMPING-OFF OF TOMATOES IN COMMERCIAL GREENHOUSES.

TREATMENT	LOCATION OF EXPERIMENT														GRAND AVERAGE PERCENTAGE OF CHECK
	Gasport		Hamburg		Hamburg		Eden		Eden		Eden		Fredonia		
	Pre-emergence disease, per cent	Average percentage of check	Pre-emergence disease, per cent	Average percentage of check	Pre-emergence disease, per cent	Average percentage of check	Pre-emergence disease, per cent	Average percentage of check	Pre-emergence disease, per cent	Average percentage of check	Pre-emergence disease, per cent	Average percentage of check	Pre-emergence disease, per cent	Average percentage of check	
Check (seeds untreated)...	26.6		25.6		42.4		30.5		31.3		52.7		39.5		
Check (seeds untreated)...	32.5		38.4		45.1		31.6		26.0		24.1		40.1		
Average....	29.6	00.0	32.0	00.0	43.8	00.0	31.1	00.0	28.7	00.0	28.4	00.0	39.8		00.0
Copper sulfate monohydrate.....	14.0		14.9		13.2		14.9		12.2		21.3		11.2		
Copper sulfate monohydrate.....	12.7		23.6		15.3		22.9		20.4		17.2		18.7		
Average....	13.4	45.27	19.3	60.3	14.3	32.6	18.9	60.8	16.3	56.8	19.3	67.9	15.0	37.7	51.6

Table 3 shows clearly that copper sulfate monohydrate dust may be expected to give beneficial results in damping-off control under commercial conditions since it reduced the incidence of pre-emergence disease by 50 per cent as a mean for the seven houses from which data were obtained. The material likewise gave better stands of tomatoes in two other houses in which it was tried at the same time but from which numerical results are not available. Examination of the roots of seedlings from treated seed showed in all cases that the treatment had kept them whiter. The results presented in Table 3 are of value also in showing that the material is non-injurious even when seeds are planted in relatively dry soil, such as that generally used in commercial houses, a fact that has considerable practical significance.

EFFECT OF DILUTION

Having ascertained that the material was effective in damping-off control in the undiluted form, it was tested in various dilutions to see how weak it could be used without loss of efficiency. The results from one experiment using kaolin as a diluent appear in Table 4.

Table 4 shows that the material can be diluted safely with 3 parts of kaolin without diminishing its value, since the minimum effective dosage seems to be below a dilution of 25 per cent when the seeds are thoroly coated. Several tests, however, would be needed to decide within a fairly wide range just what the minimum effective dosage would be.

Since there appeared to be some question concerning the effect of dilution upon the efficiency of the bluestone soak, one test of this point was made. At the same time, also, a wet check was contrasted with the usual dry check in order to ascertain if part of the beneficial results might not come from the mere soaking of the seeds. The results of this test appear in Table 5.

The data in Table 5 indicate that a dilution as low as 1 per cent of copper sulfate crystals in distilled water was not as efficient as a 10 per cent solution in combating damping-off. Also, they show that the mere soaking has no significance in helping to explain the beneficial effect of the copper sulfate soak treatment. Alexander, *et al.*,[8] showed recently that diluting copper sulfate solution decreased its effectiveness.

[8] *Loc. cit.*

TABLE 4.—EFFECT OF SEED TREATMENT WITH VARIOUS DILUTIONS OF COPPER SULFATE MONOHYDRATE DUST IN KAOLIN FOR COMBATING DAMPING-OFF OF TOMATOES.

TREATMENT	PERCENTAGE OF $CuSO_4 \cdot 1H_2O$	NUMBER OF SEEDS PLANTED	NUMBER OF SEEDLINGS EMERGED	EMERGENCE, PER CENT	PRE-EMERGENCE DISEASE, PER CENT	AVERAGE PERCENTAGE OF CHECK	POST-EMERGENCE DISEASE, PER CENT	AVERAGE PERCENTAGE OF CHECK
Check (untreated)...	00.0	1,600	921	57.6	42.4		53.0	
Check (untreated)...	00.0	1,600	918	57.4	42.6		41.0	
Average.....	——	——	——	57.5	42.5	100.0	47.0	——
Kaolin alone.....	00.0	1,600	772	48.2	51.8		53.5	
Kaolin alone.....	00.0	1,600	923	57.7	42.3		49.0	
Average.....	——	——	——	53.0	47.0	110.5	51.3	109.1
Seeds treated.....	12.5	1,600	1,095	68.4	31.6		49.5	
Seeds treated.....	12.5	1,600	1,280	80.0	20.0		35.0	
Average.....	——	——	——	74.2	25.8	60.7	42.3	90.0
Seeds treated.....	25.0	1,600	1,314	82.1	17.9		47.5	
Seeds treated.....	25.0	1,600	1,384	86.5	13.5		33.5	
Average.....	——	——	——	84.3	15.7	36.9	40.5	86.1
Seeds treated.....	50.0	1,600	1,337	83.6	16.4		31.5	
Seeds treated.....	50.0	1,600	1,136	71.0	29.0		47.5	
Average.....	——	——	——	77.3	22.7	53.4	39.5	84.0
Seeds treated.....	100.0	1,600	1,250	78.1	21.9		37.5	
Seeds treated.....	100.0	1,600	1,231	76.9	23.1		31.5	
Average.....	——	——	——	77.5	22.5	52.9	34.5	73.4

TABLE 5.—EFFECT OF SOAKING SEEDS FOR 1 HOUR IN VARIOUS DILUTIONS OF COPPER SULFATE IN WATER FOR COMBATING DAMPING-OFF OF TOMATOES IN NATURALLY CONTAMINATED SOIL.

TREATMENT	$CuSO_4 \cdot 5H_2O$, PER CENT	NUMBER OF SEEDS PLANTED	NUMBER OF SEEDLINGS EMERGED	EMERGENCE, PER CENT	PRE-EMERGENCE DISEASE, PER CENT	AVERAGE PERCENTAGE OF WET CHECK	POST-EMERGENCE DISEASE, PER CENT	AVERAGE PERCENTAGE OF WET CHECK
Dry check (untreated)	00.0	2,000	765	38.3	61.7		53.0	
Dry check (untreated)	00.0	2,000	962	48.1	51.9		41.0	
Average	——	——	——	43.2	56.8	93.4	47.0	00.0
Wet check (in water)	00.0	2,000	850	42.5	57.5		54.5	
Wet check (in water)	00.0	2,000	714	35.7	64.3		56.5	
Average	——	——	——	39.1	60.8	100.0	55.5	118.08
Seeds soaked	0.01	2,000	1,063	53.2	46.8		30.5	
Seeds soaked	0.01	2,000	1,061	53.1	46.9		26.5	
Average	——	——	——	53.2	46.8	77.0	28.5	51.4
Seeds soaked	0.50	2,000	1,099	55.0	45.0		60.5	
Seeds soaked	0.50	2,000	976	48.8	51.2		50.5	
Average	——	——	——	52.4	47.6	78.3	55.5	100.0
Seeds soaked	1.00	2,000	1,107	55.4	44.6		52.5	
Seeds soaked	1.00	2,000	1,311	65.2	34.8		43.5	
Average	——	——	——	60.3	39.7	65.3	48.0	86.5
Seeds soaked	10.00	2,000	1,430	71.5	28.5		23.5	
Seeds soaked	10.00	2,000	1,463	73.2	26.8		35.0	
Average	——	——	——	72.4	27.6	45.4	29.3	52.8

TABLE 6.—COMPARISON OF MONOHYDRATE WITH ANHYDROUS COPPER SULFATE DUSTS AS SEED TREATMENTS FOR COMBATING DAMPING-OFF OF TOMATOES IN NATURALLY CONTAMINATED SOIL.

TREATMENT	NUMBER OF SEEDS PLANTED	NUMBER OF SEEDLINGS EMERGED	EMERGENCE, PER CENT	PRE-EMERGENCE DISEASE, PER CENT	AVERAGE PERCENTAGE OF CHECK	POST-EMERGENCE DISEASE, PER CENT	AVERAGE PERCENTAGE OF CHECK
Check (untreated)...	2,000	997	49.9	50.1		68.5	
Check (untreated)...	2,000	659	33.0	67.0		48.0	
Average.....	——	——	41.5	58.5	100.0	58.3	100.0
Anhydrous.....	2,000	1,726	86.3	13.7		16.5	
Anhydrous.....	2,000	1,221	62.1	37.9		37.5	
Average.....	——	——	74.2	25.8	44.1	27.0	36.3
Monohydrate.....	2,000	1,768	88 4	11.6		22.0	
Monohydrate.....	2,000	1,671	83.5	16.5		14.5	
Average.....	——	——	86.0	14.0	23.9	18.3	31.4

COMPARISON OF MONOHYDRATE WITH ANHYDROUS COPPER SULFATE DUSTS

It seemed of interest to compare the two dust forms of copper sulfate, *viz.*, monohydrate and anhydrous, with each other as seed treatments for damping-off control. The data from a single comparison of the undiluted materials appear in Table 6.

Altho one of the duplicates of the anhydrous treatment did not hold up as well as the other, nevertheless, it would appear from the data in Table 6 and from other observations, that one dust is as efficient as the other, at least in the undiluted form. This test is of significance mostly to show yet again how very resistant tomato seeds are to copper toxicity. Even anhydrous dust, as pure a form of copper sulfate as it is, was not injurious to the stand. Furthermore, it seemed to stick better to the seeds than the monohydrate dust.

QUANTITY OF COPPER SULFATE MONOHYDRATE ADHERING TO TOMATO SEEDS

In order to obtain a rough idea regarding the quantity of copper sulfate monohydrate dust that would stick to tomato seeds, one test was made. Three measures of approximately 1,600 tomato seeds each of the variety John Baer were weighed and then shaken with a uniform excess of dust in the usual way in a 250-ml Erlenmeyer flask. The excess dust was removed by screening, after which the seeds

TABLE 7.—AMOUNT OF COPPER SULFATE MONOHYDRATE DUST THAT ADHERES TO TOMATO SEEDS.

SAMPLE NO.	WEIGHT IN GRAMS				
	Seed	Seed + dust	Dust retained		
			Total	Per seed	Per gram of seed
1	5.150	5.295	0.145	0.00009	0.0282
2	4.955	5.188	0.233	0.00015	0.0470
3	5.067	5.257	0.190	0.00012	0.0375
Av.	5.057	5.257	0.189	0.00012	0.0374

were weighed again, thus determining the weight of the dust that adhered. The agreement between the triplicates shown in Table 7 indicates that the method is sufficiently accurate.

Five grams of John Baer tomato seeds retained slightly less than

0.2 gram of copper sulfate monohydrate dust or 37 mgm of dust per gram of seed. Stated in another way, each seed retained slightly more than 0.1 mgm of dust. Expressed in common units, 1 pound of

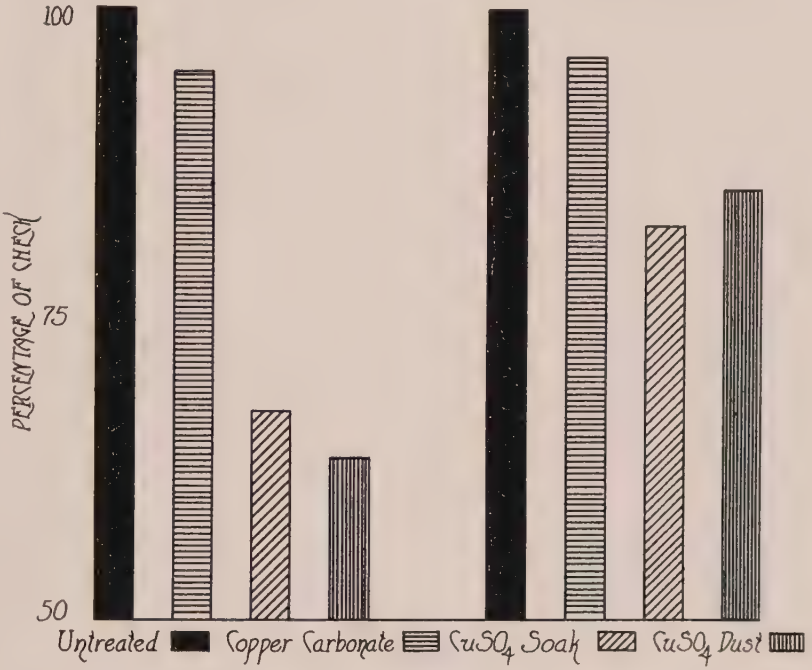

FIG. 5.—A COMPARISON BETWEEN COPPER SULFATE MONOHYDRATE DUST, COPPER SULFATE SOAK, AND COPPER CARBONATE DUST AS SEED TREATMENTS FOR COMBATING DAMPING-OFF OF TOMATOES IN SOIL ARTIFICIALLY CONTAMINATED WITH *Pythium ultimum*.

Pre-emergence disease at the left, post-emergence disease at the right.

the seed retained 0.64 ounce of dust. In practise, it is convenient to use 1 tablespoonful of dust for each pound of seed.

USE OF ARTIFICIALLY CONTAMINATED SOIL

As pointed out earlier, it seems advisable to check the results from naturally contaminated soil by using soil that has been steamed and then contaminated with a pure culture of the organism responsible for the damping-off, *Pythium ultimum* in this case. In Table 8 appear the data from two experiments in which treated seed were sown in

soil thus contaminated a week before planting by adding to it 100 grams per flat of inoculum growing on sterilized wheat kernels. These data appear also in the graph shown in Fig. 5.

As shown in Table 8 and Fig. 5, the use of soil with such a high,

TABLE 8.—COMPARISON OF COPPER SULFATE MONOHYDRATE DUST WITH COPPER BATING DAMPING-OFF OF TOMATOES IN SOIL ARTI-

No. of experiment	Check (untreated)			Dusted with copper sulfate monohydrate				
		Diseased			Diseased			
					Pre-emergence		Post-emergence	
	Emergence, per cent	Pre-emergence disease, per cent	Post-emergence disease, per cent	Emergence, per cent	Per cent	Average percentage of check	Per cent	Average percentage of check
				October 1, 1930				
1 a	2.5	97.5	96.0	24.6	75.4		89.5	
1 b	5.6	94.4	91.0	26.2	73.8		88.5	
Average	4.1	95.9	93.5	25.4	74.6	77.8	89.0	95.2
1 c	——	——	——	——	——		——	
1 d	——	——	——	——	——		——	
Average	——	——	——	——	——	——	——	——
				November 12, 1930				
2 a	21.7	78.3	99.0	65.7	34.3		76.0	
2 b	15.8	84.2	99.5	55.7	44.3		75.0	
Average	18.8	81.2	99.3	60.7	39.3	48.4	75.5	76.0
Grand average	11.4	88.1	96.4	43.05	——	63.1	——	85.6

*15 grams $CuSO_4 \cdot 5\ H_2O$ dissolved in 100 cc water.
† 5 grams $CuSO_4 \cdot 5\ H_2O$ dissolved in 100 cc water.
‡10 grams $CuSO_4 \cdot 5\ H_2O$ dissolved in 100 cc water.

unhampered fungus content reduced greatly the absolute value of the treatments, but the relative differences between the treatments are in essential agreement with those given in Table 1 based on naturally contaminated soil. With either soil the copper sulfate monohydrate dust was superior to the copper sulfate soak in combating the pre-emergence phase, but inferior in combating the post-emergence phase. The ratios between the two in this case are 0.93 and 1.04 instead of 0.68 and 1.80, respectively, as in the naturally contaminated soil. Altho the ratios do not agree numerically, they

do agree qualitatively, indicating their general correctness. The difference in the ratios for the two soils was probably due to the difference in inoculum potential. Also, the results shown in Table 8 and in Fig. 5 confirm those in Table 1 and Fig. 2, showing that copper

SULFATE SOAK AND COPPER CARBONATE DUST AS A SEED TREATMENT FOR COMFICIALLY CONTAMINATED WITH *Pythium ultimum*.

SOAKED 1 HOUR IN COPPER SULFATE SOLUTION					DUSTED WITH COPPER CARBONATE				
	Diseased					Diseased			
	Pre-emergence		Post-emergence			Pre-emergence		Post-emergence	
Emergence, per cent	Per cent	Average percentage of check	Per cent	Average percentage of check	Emergence, per cent	Per cent	Average percentage of check	Per cent	Average percentage of check
					October 1, 1930				
13.9*	86.1		99.0		5.4	94.6		96.2	
23.7*	76.3		82.0		9.3	90.7		95.1	
18.8	81.2	84.7	90.1	96.4	7.4	92.6	96.6	95.7	102.4
33.3†	66.7		80.0		——	——		——	
31.8†	68.2		88.5		——	——		——	
32.6	67.4	70.3	84.3	90.2	——	——	——	——	——
					November 12, 1930				
67.0‡	33.0		30.0		20.3	79.7		99.0	
55.1‡	44.9		90.0		29.0	71.0		78.0	
61.1	38.9	47.9	60.0	60.4	24.7	75.3	92.7	88.5	89.1
37.47	——	67.6	——	82.3	16.0	——	94.7	——	95.8

carbonate dust is inferior to both the soak and the monohydrate dust in the control of both phases of damping-off.

USE OF STEAMED UNCONTAMINATED SOIL

As a further check on these treatments, particularly as regards their injuriousness, they were used on tomato seed sown in steamed soil that had not been subsequently contaminated with a fungus pathogenic to tomatoes. The use of such soil should bring out any injurious qualities of the treatments as well as any other possible

TABLE 9.—EFFECT OF SEED TREATMENT WITH COPPER SULFATE MONOHYDRATE DUST, COPPER SULFATE SOAK, AND COPPER CARBONATE DUST ON EMERGENCE OF TOMATO SEEDLINGS FROM STEAMED UNCONTAMINATED SOIL.

No. of experiment	Check (untreated)	Dusted with copper sulfate monohydrate		Soaked in copper sulfate solution				Dusted with copper carbonate	
		Emergence, per cent	Average percentage of check	Strength of solution, per cent	Length of treatment, hours	Emergence, per cent	Average percentage of check	Emergence, per cent	Average percentage of check
				September 18, 1930					
1 a	75.9	80.3		5	1	93.6		84.0	
1 b	86.9	86.7		5	1	75.5			
Av.	81.4	83.5	102.6	——	——	84.6	103.9	84.0	103.2
1 c	——	——		2	1	96.8		——	
1 d	——	——		2	1	81.5		——	
Av.	——	——	——	——	——	89.2	109.6	——	——
				September 26, 1930					
3 a	90.1	——		5	1	78.6		84.1	
3 b	84.9	——		5	1	84.6		85.0	
Av.	87.5	——	——	——	——	81.6	93.3	84.6	96.7
				November 1, 1930					
4 a	90.0	——		10	1	78.3		83.1	
4 b	96.3	——		10	1	86.5		90.1	
Av.	93.2	——	——	——	——	82.4	88.4	86.6	92.9
Grand average...	87.4	——	102.6	——	——	——	98.3	——	97.6

effects in the absence of the fungus, such as increasing the size or deepening the color of the plants. The emergence data from three such tests with copper sulfate monohydrate dust, copper sulfate soak and copper carbonate dust appear in Table 9.

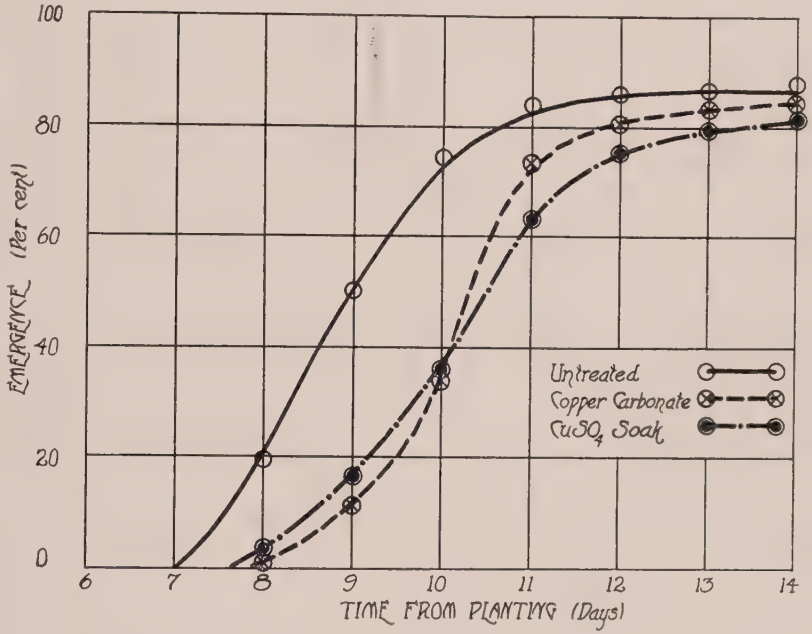

Fig. 6.—The Effect of Seed Treatment with Copper Sulfate Soak and Copper Carbonate Dust on Rate of Emergence of Tomato Seedlings from Steamed, Uncontaminated Greenhouse Soil.

Table 9 shows, as had been expected, that the treatments exerted no beneficial effects on emergence of tomato seedlings from soil in which the rot-producing organisms had been killed by steam. The tests indicated also that the increased height of the plants illustrated in Fig. 4 was not due to direct chemical stimulation by the copper, for in steamed soil the plants from treated seeds were not taller than those from untreated seeds. On the contrary, they were shorter, indicating slight injury. Presumably under ordinary conditions, the effect of the copper seed treatment is a resultant of two effects—one slightly injurious and the other rather beneficial.

The slight injurious effect of the treatments was noticed more as a

retarding influence on emergence rather than as a reduction in total stand. Two experiments (Nos. 2 and 3 in Table 9) were designed to measure this retarding influence. Tomato seeds were planted in the usual way in steamed uncontaminated soil, but instead of waiting

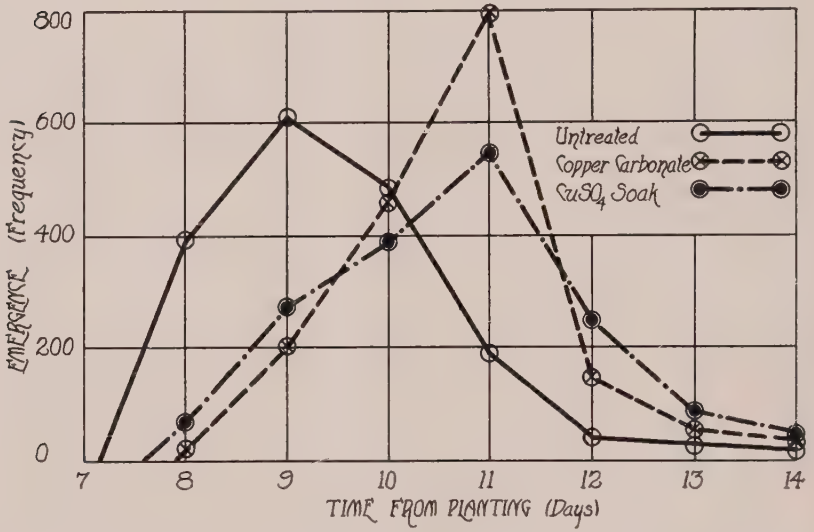

FIG. 7.—FREQUENCY CURVES SHOWING THE LAG IN EMERGENCE OF TOMATO SEEDLINGS FROM SEEDS TREATED WITH COPPER SULFATE SOAK ANDWITH COPPER CARBONATE DUST AND SOWN IN STEAMED UNCONTAMINATED GREENHOUSE SOIL.

until all of the seedlings had emerged, those that came up were severed at the ground line each morning between 8 and 9 o'clock, counted, and removed. Thus, the lag in the emergence curve could be measured. The data obtained in experiment No. 2 in Table 9 appear in Table 10. The weighted average temperature determined at 2-hour intervals from a thermograph chart during the period of the experiment was 62.5°F. The emergence curve plotted from these data appears in Fig. 6.

Fig. 6 shows clearly the lag in the emergence curve of the seedlings from the copper-treated seed. The frequency curves for the data appearing in Table 10 are plotted in Fig. 7, which shows that the mean of the emergence of the treated seed was delayed about 2 days more than the check under these conditions.

TABLE 10.—EFFECT OF SEED TREATMENT WITH COPPER SULFATE SOLUTION AND WITH COPPER CARBONATE DUST UPON THE RATE OF EMERGENCE OF TOMATO SEEDLINGS FROM STEAMED UNCONTAMINATED GREENHOUSE SOIL.

Duplicates		On 8th day	Days after planting: 9		10		11		12		13		14	
			On 9th day	Total	On 10th day	Total	On 11th day	Total	On 12th day	Total	On 13th day	Total	On 14th day	Total
	Check, Untreated													
A	Seedlings emerged	595	696	1,291	343	1,634	115	1,749	24	1,773	17	1,790	11	1,801
B	Seedlings emerged	188	519	707	631	1,338	258	1,596	51	1,647	26	1,673	25	1,698
	Average	392	608	1,000	482	1,486	187	1,673	37	1,710	22	1,732	18	1,750
	Per cent	19.6	—	50.0	—	74.3	—	83.7	—	85.5	—	86.6	—	87.5
	Copper Sulfate Solution, 5 per cent, 1 Hour													
A	Seedlings emerged	125	415	540	431	971	385	1,356	146	1,502	42	1,544	28	1,572
B	Seedlings emerged	6	111	117	341	458	704	1,162	349	1,511	124	1,635	57	1,692
	Average	66	263	329	386	715	544	1,259	248	1,507	83	1,590	42	1,632
	Per cent	3.3	—	16.5	—	35.8	—	63.0	—	75.4	—	79.5	—	81.6
	Copper Carbonate Dust													
A	Seedlings emerged	29	210	239	409	648	815	1,463	122	1,585	61	1,646	36	1,682
B	Seedlings emerged	10	193	303	500	703	772	1,475	165	1,640	42	1,682	17	1,699
	Average	20	201	221	455	676	793	1,469	144	1,613	51	1,664	27	1,691
	Per cent	1.0	—	11.1	—	33.8	—	73.5	—	80.7	—	83.2	—	84.6

APPLICATION OF THE RESULTS TO PRACTISE

From the data presented in Tables 1 and 8 it may be said that copper sulfate monohydrate is a valuable seed treatment for combating damping-off of tomatoes. It would appear to be more effective in increasing stands than the soak, but somewhat less effective in controlling the disease on the emerged seedlings. It was not designed to replace the soak treatment, but for most growers it seems easier to handle than the soak treatment. A large number of tests, as shown in Table 3, indicate that there is little to fear in using copper sulfate monohydrate dust as a treatment for tomato seed under commercial conditions.

Copper sulfate monohydrate dust as a seed treatment for tomato seeds has many advantages to growers. It is cheap and easily obtained from either the Niagara Sprayer Co., Middleport, N. Y., or the New York Insecticide Co., Medina, N. Y. It may be obtained also from the local dealer in spray materials.

The best results are obtained only by coating each seed thoroly. Mixing is accomplished conveniently by shaking violently a half pound of seed with a heaping tablespoonful of dust in a 2-quart fruit jar. "SHAKE WELL BEFORE USING" is very apropos when tomato seeds are to be dusted with copper sulfate monohydrate for damping-off control.

DISCUSSION

The severity of damping-off of unemerged seedlings has been expressed as the percentage of pre-emergence disease, meaning the percentage of seeds or seedlings that rotted before emergence. Thus, the emphasis has been placed on plant disease control where it belongs rather than on the stand. Altho no distinction has been made between the seeds that did not sprout and the seedlings that did not emerge from the soil, this might have been done by subtracting the percentage of individuals not recovered from the percentage of germination which could have been shown by seed laboratory tests. Since the severity of the post-emergence phase of the disease was based upon the number of seedlings affected, it seemed necessary to base the severity of the pre-emergence phase of the disease on the number of individuals destroyed before they could get above ground rather than on those that were able to emerge. In this way the figures for disease expression for the two phases were made com-

parable so that they varied directly with each other rather than indirectly as was the case when stand figures were used as an index of the pre-emergence phase. By these methods, it was easy to compare the relative values of any treatments for combating both phases of damping-off.

The experimental comparison between the three copper treatments, *viz.*, copper sulfate soak, copper sulfate dust, and copper carbonate dust, was made with another idea in mind than just merely to determine whether or not one was better than the other. The three materials were compared in order to obtain additional data bearing on the hypothesis suggested previously[9] that tomato seedlings may absorb sufficient copper to make themselves partially immune to damping-off. The data given in Table 1 of the paper referred to showed that the soak treatment was more efficacious than copper carbonate in controlling both phases of damping-off, but *more efficacious in controlling the post-emergence phase than the pre-emergence phase*. It was suggested that the seeds are exposed to soluble copper when the sulfate soak is used rather than to insoluble copper when the carbonate dust is used, with the result that the embryos may absorb more copper and, therefore, withstand better the damping-off after emergence. It seemed that in each case almost equal amounts of copper diffused out into the soil around each seed and thus protected them almost equally from the pre-emergence phase of the disease. The somewhat better stands from soaked seed probably indicated somewhat better diffusion of the more soluble copper.

The monohydrate dust served the purpose for this discussion of furnishing a soluble dust to compare with the soak and with the insoluble dust, copper carbonate. Before any experiments were made, it was postulated from the hypothesis just elucidated that the monohydrate dust would increase emergence even over the soak because a larger amount of soluble copper would be put into the soil around each seed. Also, it was postulated that control of damping-off after emergence would be less with the monohydrate dust than with the soak, since the embryo would have no chance to absorb copper from the dust until the latter became wet in the soil solution. By that time the embryo would be in competition for the copper with the soil organic matter, so that it probably would not be able to absorb as much as it would had the seed been placed in a copper

[9]Bulletin No. 586 of this Station.

sulfate solution. Therefore, the post-emergence disease would be more severe in the case of the monohydrate dust than in the case of the soak. It was postulated in addition that the monohydrate dust would be superior to copper carbonate in combating the latter phase. Reference to Table 1 in this bulletin will indicate how nearly correct the postulates were. The monohydrate dust showed itself to be superior to both the soak and the copper carbonate dust in increasing emergence; but seemed to be inferior to the soak, but still superior to copper carbonate dust, in controlling the post-emergence phase of damping-off. Since the data are not all statistically significant, however, they must be used with great caution.

This line of evidence is therefore considered only as evidence. In this connection, it would be well to know how much actual copper is retained by a single seed for all three materials, how much copper actually enters the embryo in each case, and how much copper diffuses from the seed into the soil in each case and to what distance. Also, it would be of interest to compare several other insoluble dusts, like the copper oxides, with copper carbonate and copper sulfate monohydrate. A knowledge of these points would shed additional light on the problem.

Since the disease on the roots of seedlings from treated seed is less severe than on seedlings from untreated seed, the increase in height and color as a result of treatment is considered to be due to disease control rather than to direct stimulation in the absence of disease as has sometimes been suggested in the literature. Any method of killing the organisms, such as steaming or treating the soil with formaldehyde or acetic acid before sowing, will give the same increased vigor and color, but in all such cases there will be less disease on the roots as well.

The effectiveness of these copper seed treatments in soil artificially contaminated with *Pythium ultimum* seems to show that their significance in normal soil may be explained largely on the basis of their action on this one organism. This conclusion, of course, cannot rule out of consideration an effect on other copper-sensitive organisms, but it probably does rule out *Rhizoctonia solani*, since this fungus does not appear to be copper sensitive, as shown by Wiant.[10] Alex-

[10]Wiant, J. S. The Rhizoctonia damping-off of conifers and its control by chemical treatment of the soil. *Cornell University Agr. Exp. Sta. Mem. 124. 1929.*

ander, *et al.*,[11] present data, however, tending to show that *Rhizoctonia solani* may be somewhat sensitive to copper.

The lag in emergence of copper-treated seeds sown in steamed soil agrees with the results obtained by Josefowicz,[12] who used baked soil.

This discussion should not close without some mention of the shortcomings of seed treatment in the control of damping-off. Excellent as are the results with the control of the post-emergence phase, they are by no means perfect. The word "combat" is used in the titles to these papers on seed treatment for damping-off to indicate that the control is not perfect, or even always commercially successful. Damping-off sometimes does occur in seedlings from treated seed, occasionally in a severe form, so that these treatments must be considered only as valuable palliatives and not as panaceas. That seed treatment is a valuable insurance, however, will be attested by a large number of plant growers in New York. Steaming soil still remains as the most effective agent for killing pathogenic fungi living therein, and probably will remain so for some time. Awkwardness, expense, and danger of recontamination, however, are serious drawbacks to its use. These justify the investigation of other methods for controlling damping-off. The pursuit for better seed treatments still goes on. Soil treatment with chemicals is being investigated also on a large scale at this Station.

SUMMARY

1. This paper is the fourth in a series of reports, each covering a phase of the writer's work on damping-off of vegetable seedlings, particularly tomatoes, as caused by *Pythium ultimum*.
2. A new term, "inoculum potential", is defined to supply a need for an expression to cover the influence of the fungus content of the soil on severity of infection irrespective of environmental factors.
3. A fairly inexpensive retort for experimental soil sterilization is described.
4. The severity of damping-off of unemerged seedlings has been expressed as percentage of seeds rotted, and labeled as percentage of pre-emergence disease, not as percentage of emerg-

[11] *Loc. cit.*

[12] Jozefowicz, M. The effect of certain treatments on the germination of tomato seeds. *Ann. Appl. Biol.*, **17**: 504–513. 1930.

ence, thus placing the emphasis on plant disease control where it belongs rather than on the stand of plants.

5. Copper sulfate monohydrate dust as a seed treatment seems to be more efficacious than either copper sulfate soak or copper carbonate dust in controlling the pre-emergence phase of damping-off. It seems to be less efficacious than the soak but more so than the copper carbonate dust in controlling the post-emergence phase. This is discussed as evidence in support of a theory of copper absorption by the seedling.
6. Copper sulfate monohydrate has been tested as a seed treatment for damping-off of tomatoes in nine greenhouses in western New York and found to be effective in eight, indifferent in one, but injurious in none.
7. Copper sulfate monohydrate may be diluted with as much as three parts of kaolin without altering its effectiveness.
8. Anhydrous copper sulfate as a seed treatment is not toxic in ordinary soil, and sticks to tomato seed better than the monohydrate dust.
9. Five grams containing 1,600 John Baer tomato seeds will retain 0.2 gram of copper sulfate monohydrate dust. In a practical way, that means about 0.6 ounce of dust for 1 pound of seed.
10. The results obtained from copper sulfate monohydrate dust, copper sulfate soak, and copper carbonate dust in soil artificially contaminated with *Pythium ultimum* agree with those obtained in naturally contaminated soil, thus indicating that this is the chief pathogene concerned in the unsteamed soil.
11. These seed treatments, when used in steamed and uncontaminated soil, induce a small lag in the emergence of the seed, delaying the mean by two days.